

An environmental chamber for hertzian fracture testing

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Abstract A test chamber for conducting hertzian indentation–fracture experiments on brittle solids in a controlled environment is described. Facility is made to evacuate the chamber, to heat the specimen and to admit a reactive gas or liquid to the specimen. The design permits a large number of runs to be made quickly, with external control of the test conditions. Some results of hertzian tests on glass are presented to indicate the means by which data for a general fracture mechanics description of environmental effects may be obtained.

1 Introduction

Recent studies of the mechanics of crack growth in the hertzian indentation test (Frank and Lawn 1967, Langitan and Lawn 1969, 1970, Mikosza and Lawn 1971) have opened the way for the development of a new fracture tool. The principle of operation is simple: a hard sphere is loaded normally on to a flat, brittle specimen surface until a cone-shaped crack forms beneath the indenter. The critical loading conditions are taken as an indicator of material strength. Apart from its simplicity, the hertzian test has several advantageous features over other tests (Langitan and Lawn 1970), chief of which are the facility to perform many experiments on the one surface and the relatively high reproducibility attainable without stringent specimen preparation. Its main disadvantage lies in the difficulty in following the initial stages of crack growth prior to full development of the cone (Mikosza and Lawn 1971) owing to the small scale of the experiment.

The development of the hertzian test comes at a time when interest in brittle fracture is being stimulated by investigations into environmental effects. The general approach involves a study of subcritical crack-growth kinetics, ultimately relatable to rate-dependent processes at the crack tip. In this paper we describe the operation of an environmental chamber designed for hertzian fracture testing under a wide range of carefully controlled conditions. The apparatus permits cone crack formation to be followed under vacuum, in the presence of a reactive atmosphere and at elevated temperatures.

2 Apparatus

The apparatus consists basically of a main test chamber, with external instrumentation to control the sequence of indentation and the environmental conditions. A prime consideration

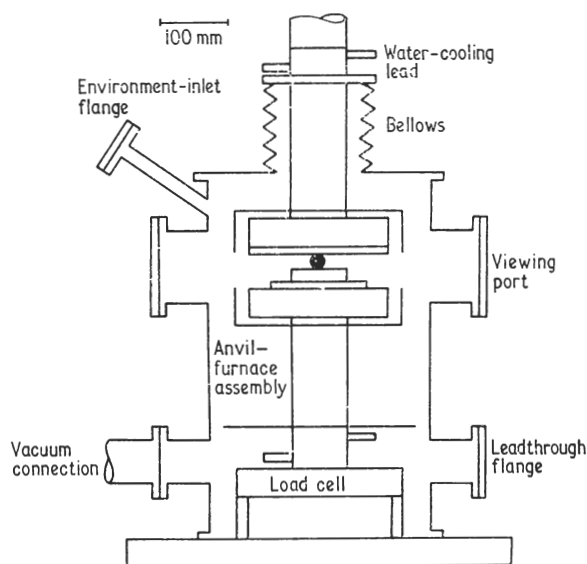


Figure 1 Test chamber

in the design is the facility to vary the test conditions and to make a large number of indentations in a short time.

2.1 Test chamber

The environmental test chamber consists of a closed stainless-steel cylinder, fitted with viewing ports and flanges connecting to the external control systems. Figure 1 shows the essential details. The specimen is housed in the anvil–furnace assembly (see §2.3), in line with the viewing ports. The lower anvil is fixed to a ram attached to a load-cell. The upper anvil, which bears on a $\frac{1}{2}$ in tungsten carbide indenting sphere, is connected by means of a second, movable ram, through stainless-steel bellows, to the loading system above. Demountable windows at the viewing ports permit a ready interchange of specimens. The furnace assembly and load cell are shielded by reflector plates, and the rams and outer chamber are water-cooled.

2.2 Indentation–control system

The main chamber may be used in conjunction with any standard testing machine capable of delivering loads up to 1000 kg, but we have incorporated a simple loading device of our own design into the equipment. A loaded trolley is driven along a pin-jointed cantilever beam, which bears on the upper ram. The practical range of load rates obtainable is $0.1\text{--}50\text{ kg s}^{-1}$. The load axis is maintained normal to the specimen surface by a bearing assembly which constrains lateral movement of the upper ram.

Measurement of the indentation load is made directly via a load cell mounted within the test chamber (see figure 1). The cell is basically a circular stainless-steel plate, loaded centrally through the lower ram, and supported circumferentially. The load is read as the output signal from a standard DC Wheatstone bridge network of strain gauges attached to the plate. The sensitivity of the load cell varies very slightly with load and temperature, and is calibrated with standard weights before each run. For a 12 V bridge input the sensitivity is $0.096 \pm 0.002\text{ mV kg}^{-1}$ for a load range $0\text{--}200\text{ kg}$ at room temperature.

The sequence of indentation testing for each run is controlled by the indenter mechanism shown in figure 2. The specimen is seated on a stainless-steel spacer to ensure the test surface is always the same height above the lower anvil. A tungsten carbide disc is spring-clamped to the under surface of the

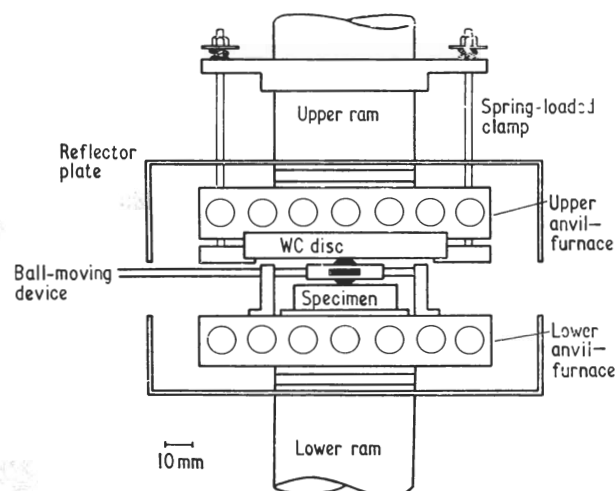


Figure 2 Detail of anvil-furnace assembly

upper anvil to prevent deformation of the assembly itself. The spherical indenter is loosely mounted in a movable frame-like device which permits accurate location of the indentation site. Manipulation of the indenter-moving device is made from outside the chamber by means of a link rod connected through a Wilson seal; rotation, and translation degrees of freedom of the link rod convert to X-Y translation of the indenter. With this arrangement well over a hundred indentations can be made on a single test surface $2 \text{ in} \times 2 \text{ in}$ without detectable interactions between neighbouring indents.

The entire indentation operation can be observed through the viewing ports. For tests to fracture on transparent materials the sudden development of the hertzian cone is visually detectable through the sides of the specimen. By manually depressing a key at this point the load-cell output to a recorder is momentarily interrupted, thereby providing a record of the critical event. For tests in which the crack growth is not optically detectable, e.g. cone formation in opaque materials, initial stages of subcritical growth in any material, the specimen is usually examined after withdrawal from the test chamber (Mikosza and Lawn 1971); more direct methods, e.g. the use of acoustic sensors to detect the stages of fast crack propagation, are receiving current attention (Wilshaw and Rothwell 1971).

2.3 Environment-control system

The components of the environment-control system are designed for maximum interchangeability. Thus, for instance, the furnace assembly described below may be readily dismantled and replaced by an alternative unit.

2.3.1 Furnace assembly The furnace is integrated into the anvil assembly shown in figure 2. The anvils themselves serve as hot plates. Electrically insulated heating coils passing through holes drilled in the plates supply up to 1000 W of power to the furnace. The main mode of heat transfer to the specimen is conduction. To minimize heat conduction along the indenter rams each hot plate is thermally insulated by an alumina disc sandwiched between two layers of mica (thermal barrier).

Two Chromel-Alumel thermocouples monitor the temperature characteristics of the furnace. The first is located within a narrow cavity in the lower hot plate, and is used to provide a signal for an external furnace-temperature controller. The second is attached to the indenter-moving device, and contacts the specimen surface at a point less than 3 mm from the

indentation site. With the present arrangement the maximum practicable specimen temperature that can be achieved is about 500°C , which covers the range of interest for most glass specimens. The furnace plates heat to optimum within minutes, but the temperature of the specimen surface generally requires several hours to approach an equilibrium value; this lag reflects the relatively low thermal conductivity of the brittle specimens used in our work. Near to equilibrium, the maximum variation in specimen surface temperature recorded during a one-hour run is less than $\pm 3^\circ\text{C}$; this variation includes recording error, drift with time and effect of translating the indenter over the specimen surface.

2.3.2 Vacuum and environment-inlet system The vacuum system consists of a standard 2 in diffusion pump with baffle and liquid nitrogen trap, backed by a two-stage mechanical pump. This permits evacuation of the main chamber to better than $10 \mu\text{Torr}$. A roughing line in the vacuum system permits the test chamber to be isolated, opened to atmosphere, and re-evacuated with minimum delay. Thus specimen replacement, with restoration of the vacuum to better than 0.1 mTorr , can be effected within 20 minutes.

Provision is made, via the environment-inlet flange of the test chamber, to admit a gas or liquid to the specimen. Where necessary, the environmental species is first passed through a purifying plant. Gases are admitted into the chamber at a controlled flow rate through a needle valve. Liquids are gravitation-fed through a long, narrow glass tube lead-through, directly into a container (replacing the spacer, figure 2) seated on the lower anvil, thereby immersing the specimen surface.

3 Performance

Some preliminary test runs have been made on plate glass slabs $2 \text{ in} \times 2 \text{ in} \times \frac{1}{8} \text{ in}$. The specimen surfaces were first abraded in a slurry of 400-grade SiC powder, to ensure a uniform layer of surface flaws for the nucleation of the hertzian fractures (Langitan and Lawn 1969). Figure 3 shows the effect of water vapour on the hertzian strength. The lines of slope unity on the logarithmic graph indicate a constant load rate, and the data points (mean value, plus standard deviation, for 10 tests) indicate the critical load to cone fracture. Each symbol in figure 3 represents a single specimen (the three specimens used here gave mutually consistent results in a control run at $10 \mu\text{Torr}$). Bearing in mind that the inverse of

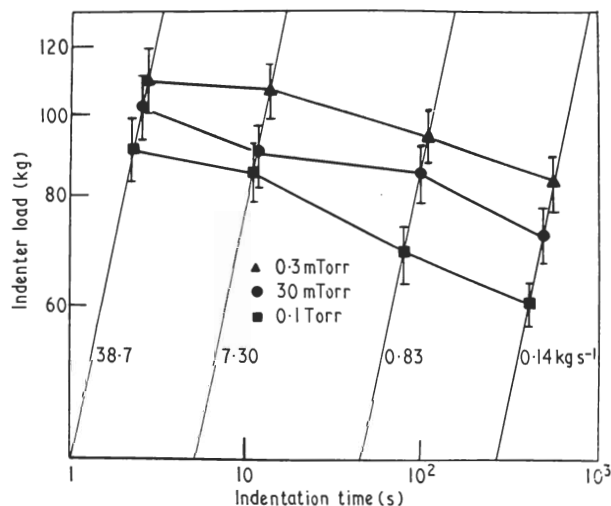


Figure 3 Results of hertzian tests at 100°C for three water-vapour pressures

the time to fracture is a measure of the average velocity of the subcritical crack, which propagates initially as a surface ring to a critical depth prior to full development of the cone (Mikosza and Lawn 1971), the influence of concentration of the reactive environment on crack-growth kinetics is apparent. Such data provide an experimental basis for a fracture mechanics description of environmental effects in brittle solids.

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